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Improved Tangent-Cone Method for the Aerodynamic Preliminary Analysis System (APAS) Version of the Hypersonic Arbitrary-Body Program

Sova

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**Improved Tangent-Cone Method
for the Aerodynamic Preliminary
Analysis System (APAS)
Version of the Hypersonic
Arbitrary-Body Program**

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Abstract

The Aerodynamic Preliminary Analysis System (APAS) utilizes a modified version of the Hypersonic Arbitrary-Body Program (HABP) Mark III code in its analysis rationale. Four methods are considered for incorporation into the code as the tangent-cone method. The combination of second-order slender body theory and the approximate solution of Hammitt and Murthy shows the best agreement with the exact numerical solutions and is thus included in the APAS production version of the HABP code.

Introduction

The Aerodynamic Preliminary Analysis System (APAS, refs. 1 and 2) uses a modified version of the Hypersonic Arbitrary-Body Program (HABP) Mark III code (ref. 3) in its analysis rationale. An integral part of such an analysis is the calculation of inviscid pressure distributions on arbitrary surfaces. Vehicle fuselages are often somewhat conical in shape; thus a method of predicting pressure drag for such shapes is required.

Four impact pressure methods are evaluated for their ability to predict the zero-angle-of-attack inviscid pressure coefficients of sharp cones with angles of 5°, 7.5°, 10°, 12.5°, 15°, 17.5°, 20°, 30°, 40°, and 50°. These predictions are then compared with the exact solution for air. Finally, a method is chosen for use in the APAS production version of the HABP code.

Symbols

C_p	pressure coefficient, $(p - p_\infty)/q_\infty$
K	constant in Newtonian pressure coefficient equation
M_{ns}	Mach number normal to the shock
M_∞	free-stream Mach number
p	local pressure, lbf/ft ²
p_∞	free-stream pressure, lbf/ft ²
q_∞	dynamic pressure, $\frac{1}{2}\rho_\infty V_\infty^2$
V_∞	free-stream velocity, ft/sec
δ	impact angle, deg
θ_c	cone half-angle, deg
θ_s	shock angle, deg
γ	ratio of specific heats
ρ_∞	free-stream density, lbm/ft ³

Description of Prediction Methods

The four impact methods evaluated for pressure coefficient prediction were (1) Newtonian theory (ref. 3), (2) the original HABP Mark III tangent-cone empirical method (ref. 3), (3) the Edwards tangent-cone empirical method (ref. 4), and (4) a combination of second-order slender-body theory and the approximate cone solution of Hammitt and Murthy (ref. 5).

Modified Newtonian theory yields a pressure coefficient which is a function only of impact angle:

$$C_p = K \sin^2 \delta$$

where K is equal to the stagnation-point pressure coefficient (ref. 6).

Both the HABP Mark III and the Edwards versions of the tangent-cone empirical method calculate pressure coefficient as a function of Mach number and impact angle:

$$C_p = \frac{48M_{ns}^2 \sin^2 \delta}{23M_{ns}^2 - 5}$$

The difference between these two methods lies in the empirical equations for Mach number normal to the shock. For the HABP Mark III version,

$$M_{ns} = 1.090909M_\infty \sin \delta + \exp(-1.090909M_\infty \sin \delta)$$

For the Edwards version,

$$M_{ns} = (0.87M_\infty - 0.544) \sin \delta + 0.53$$

The last method uses a combination of second-order slender-body theory and the approximate cone solution of Hammitt and Murthy. The pressure coefficient found with this method is given by

$$C_p = \frac{p_\infty}{\frac{1}{2}\rho_\infty V_\infty^2} \left(\left(\frac{2\gamma}{\gamma+1} M_\infty^2 \sin^2 \theta_s - \frac{\gamma-1}{\gamma+1} \right) \left\{ 1 + \frac{\gamma M_\infty (\theta_s - \theta_c)^2 \cos^2 \theta_s}{1 + [(\gamma-1)/2] M_\infty^2 \sin^2 \theta_s} \right\}^{-1} \right)$$

Results and Discussion

Figures 1 to 10 present inviscid pressure coefficients (zero angle of attack) for sharp cones with half-angles from 5° to 50° and Mach numbers from 1.5 to 25. Each figure contains pressure coefficients calculated with each of the four prediction methods as well as exact values from the tables of Kopal (ref. 7) and Jones (ref. 8).

For all cone half-angles investigated, Newtonian theory underpredicts pressure coefficient throughout the entire Mach number range. Adjustment of the Newtonian constant from $K = 2$ to $K = 2(\gamma + 1) \times (\gamma + 7)/(\gamma + 3)^2$ (ref. 1) would give a reasonable result for Mach numbers greater than 10, when the inviscid pressure coefficient is relatively constant with respect to Mach number.

The HABP Mark III tangent-cone empirical method does a better job than Newtonian theory, but at Mach numbers less than 5 it also greatly underpredicts the exact solutions, as shown in figures 7 to 10.

The Edwards tangent-cone empirical method is a vast improvement over the HABP Mark III method. At smaller cone half-angles, results from the Edwards method match the exact values closely for Mach numbers of 1.5 and up. However, as cone half-angle increases, the discrepancy between the results from the Edwards method and the exact values grows larger.

By far, the best of the methods evaluated is that referred to in figures 1 to 10 as the "2nd Order Slender Body + Hammitt/Murthy" method. With few exceptions, this method predicts the inviscid pressure coefficient at zero angle of attack with great accuracy. (In most cases, there is less than 1 percent difference between predictions and the exact values of Kopal and Jones.) Figures 9 and 10 show the peculiarities which can occur when this method is used for large cone half-angles. This degeneration of calculated pressure coefficient corresponds to the physical existence of detached shocks for larger cone half-angles at low supersonic speeds. It is important to note, however, that even with these discontinuities, this method is still far superior to the other three methods considered.

Conclusions

The combination of second-order slender-body theory and the approximate cone solution of Hammitt and Murthy is the superior method of those eval-

uated. It is thus included in the Aerodynamic Preliminary Analysis System (APAS) production version of the Hypersonic Arbitrary-Body Program (HABP) code as the tangent-cone method. The Newtonian theory, original HABP Mark III tangent-cone, and Edwards tangent-cone methods all have applicability within given restrictions, but outside of these restrictions they may yield misleading results.

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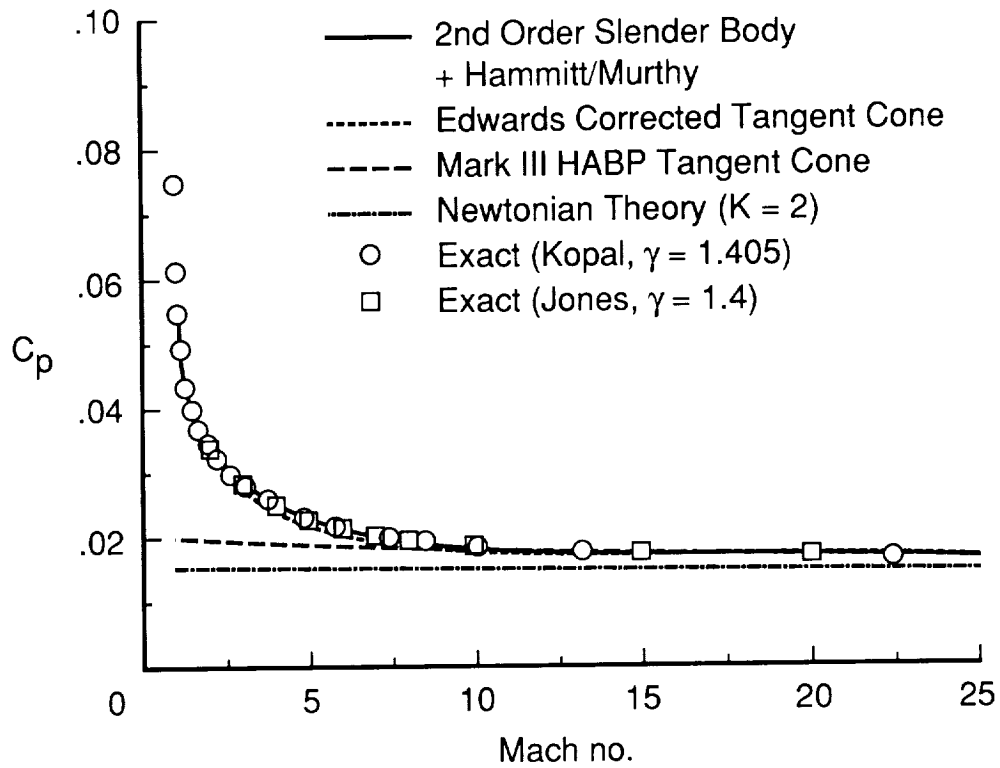


Figure 1. Pressure coefficient versus Mach number for 5° sharp cone.

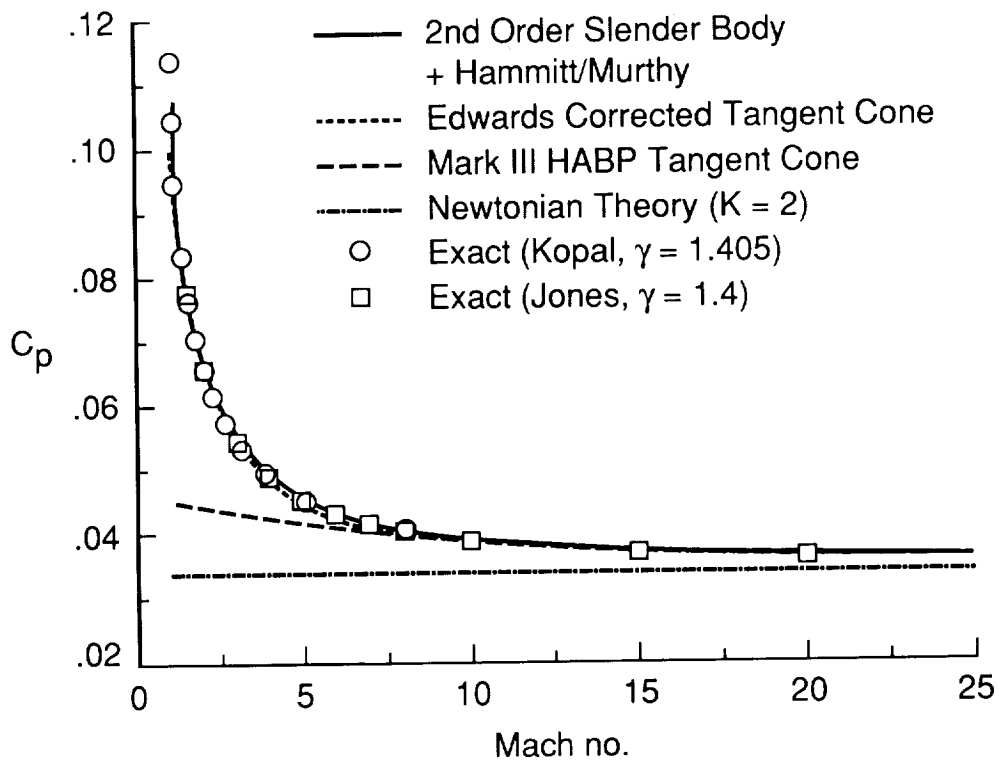


Figure 2. Pressure coefficient versus Mach number for 7.5° sharp cone.

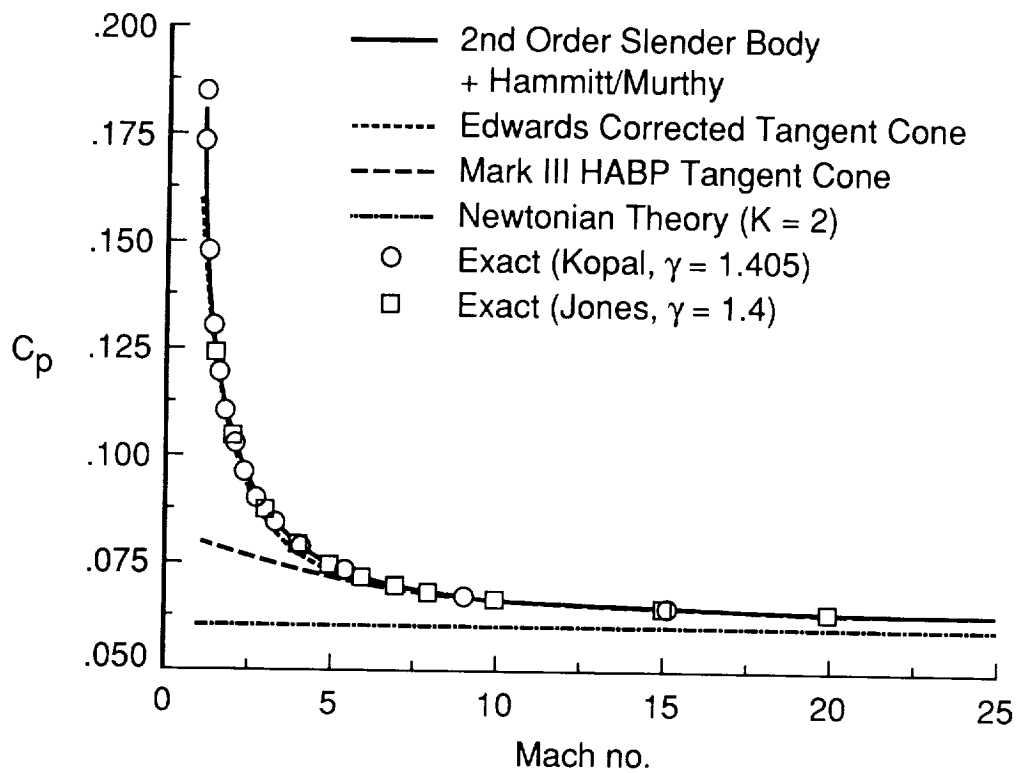


Figure 3. Pressure coefficient versus Mach number for 10° sharp cone.

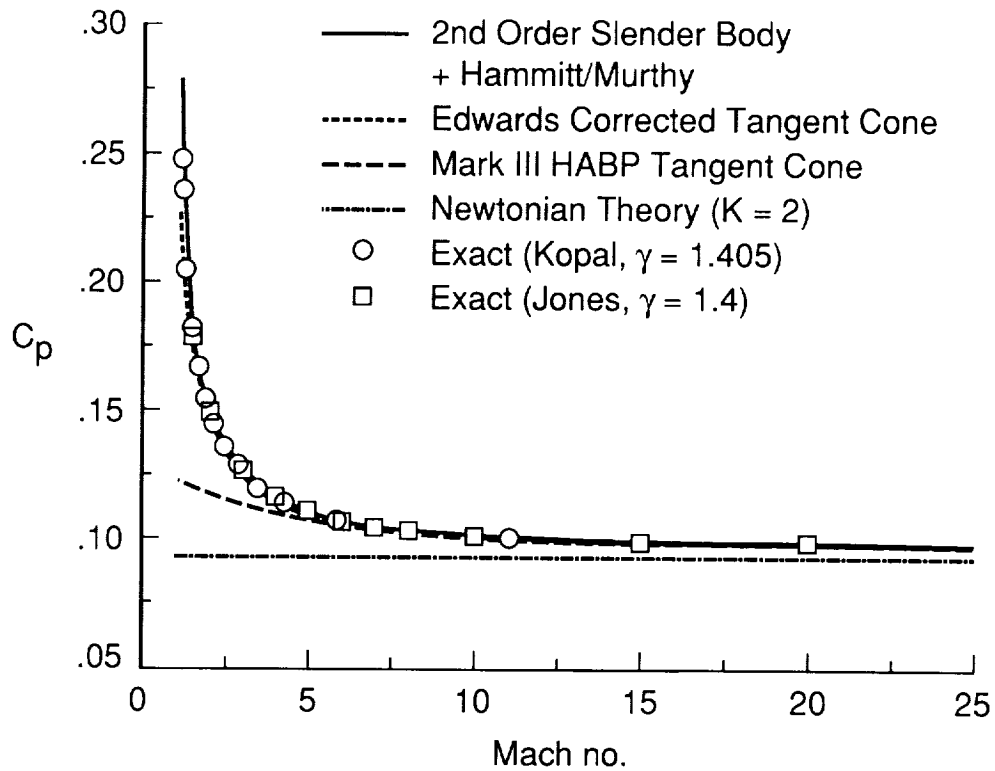


Figure 4. Pressure coefficient versus Mach number for 12.5° sharp cone.

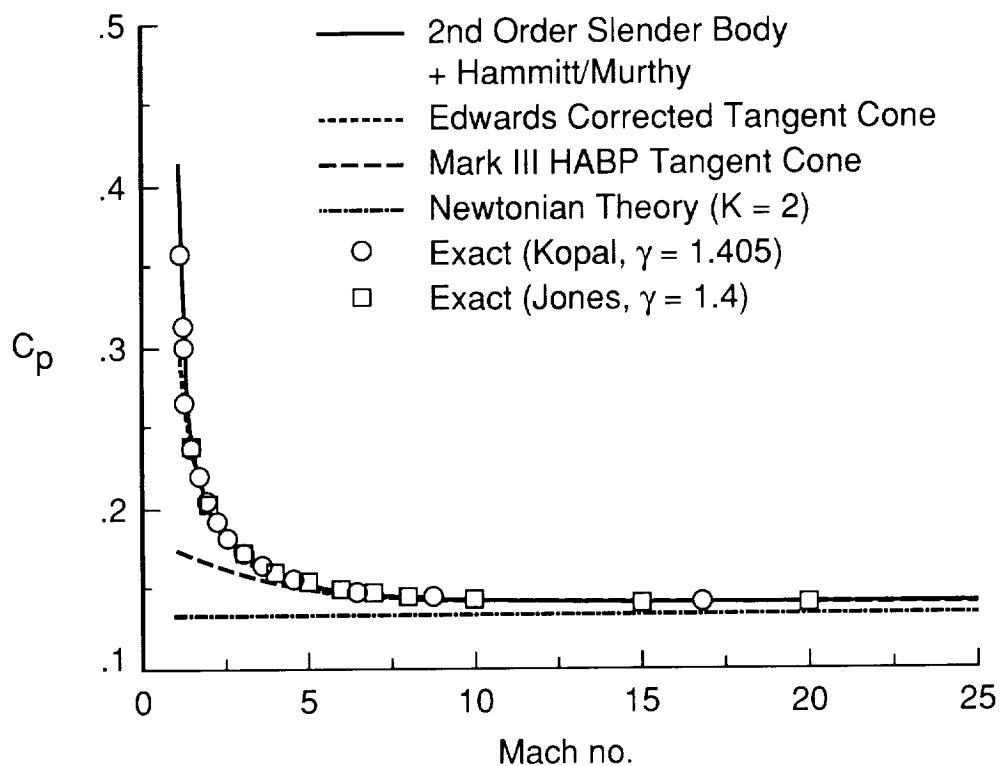


Figure 5. Pressure coefficient versus Mach number for 15° sharp cone.

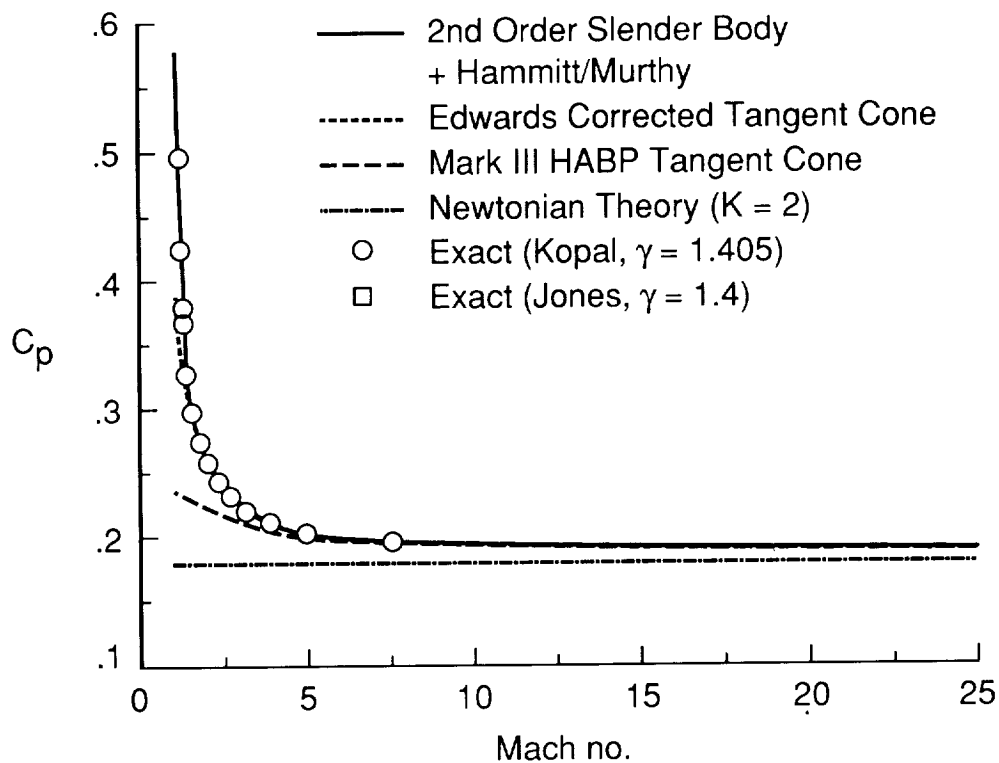


Figure 6. Pressure coefficient versus Mach number for 17.5° sharp cone.

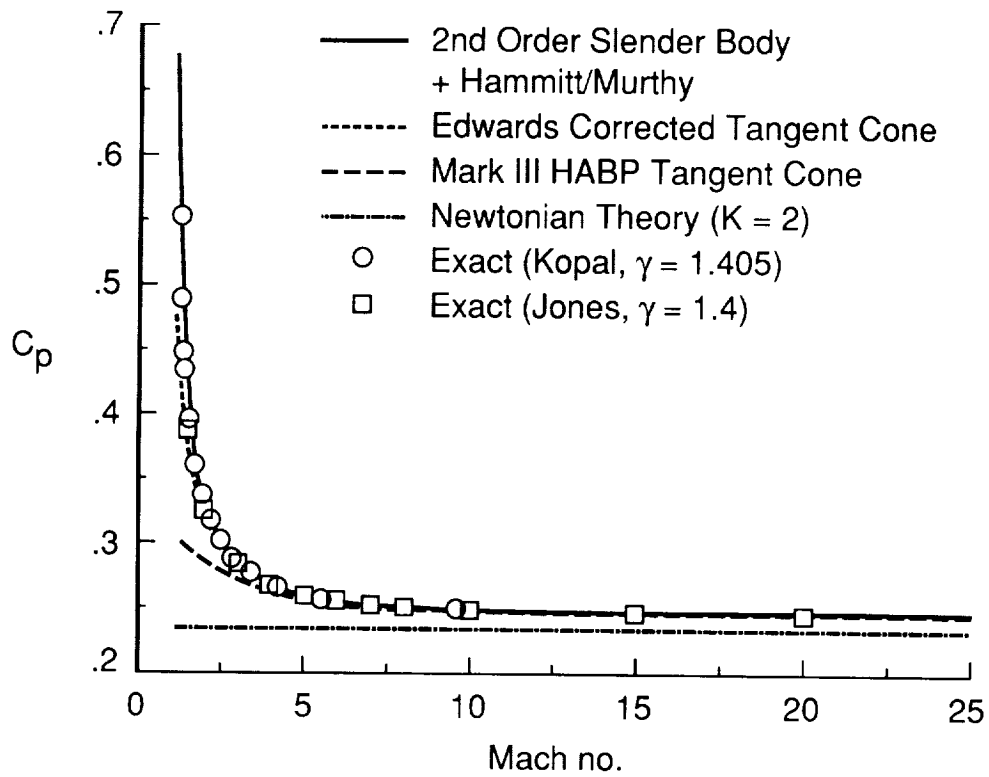


Figure 7. Pressure coefficient versus Mach number for 20° sharp cone.

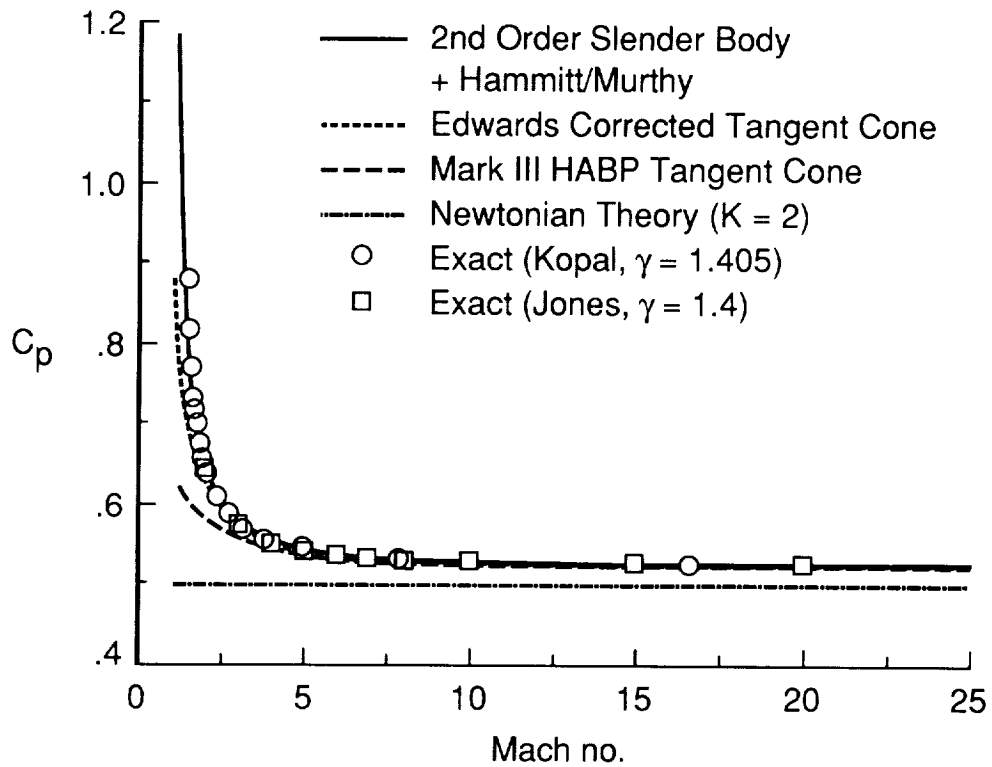


Figure 8. Pressure coefficient versus Mach number for 30° sharp cone.

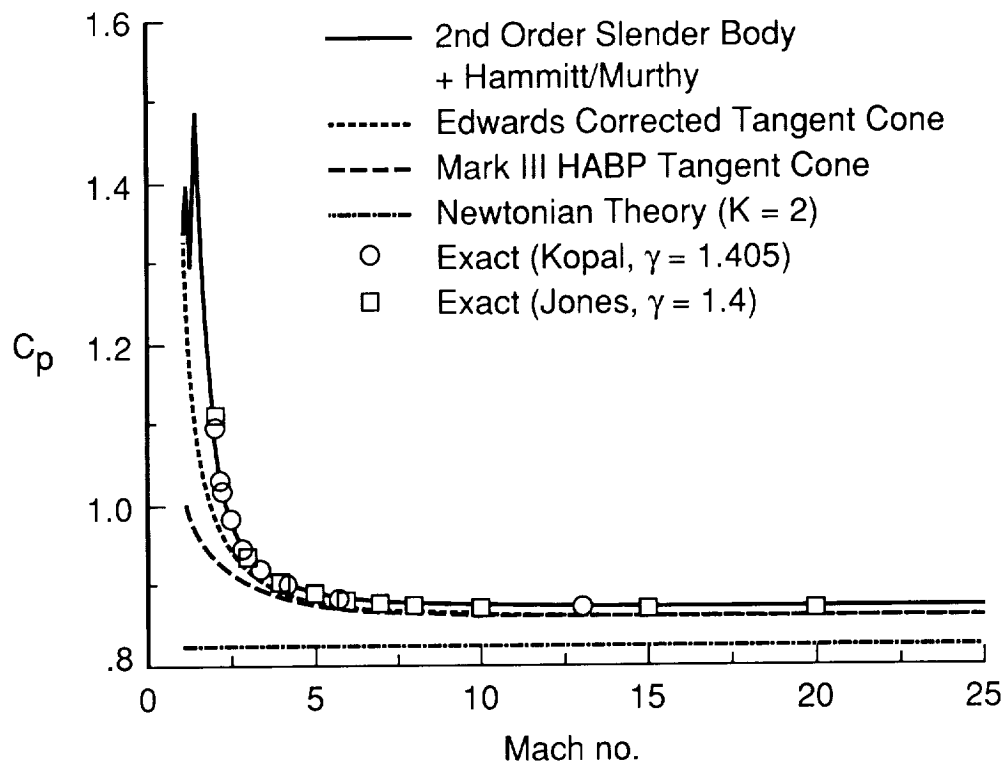


Figure 9. Pressure coefficient versus Mach number for 40° sharp cone.

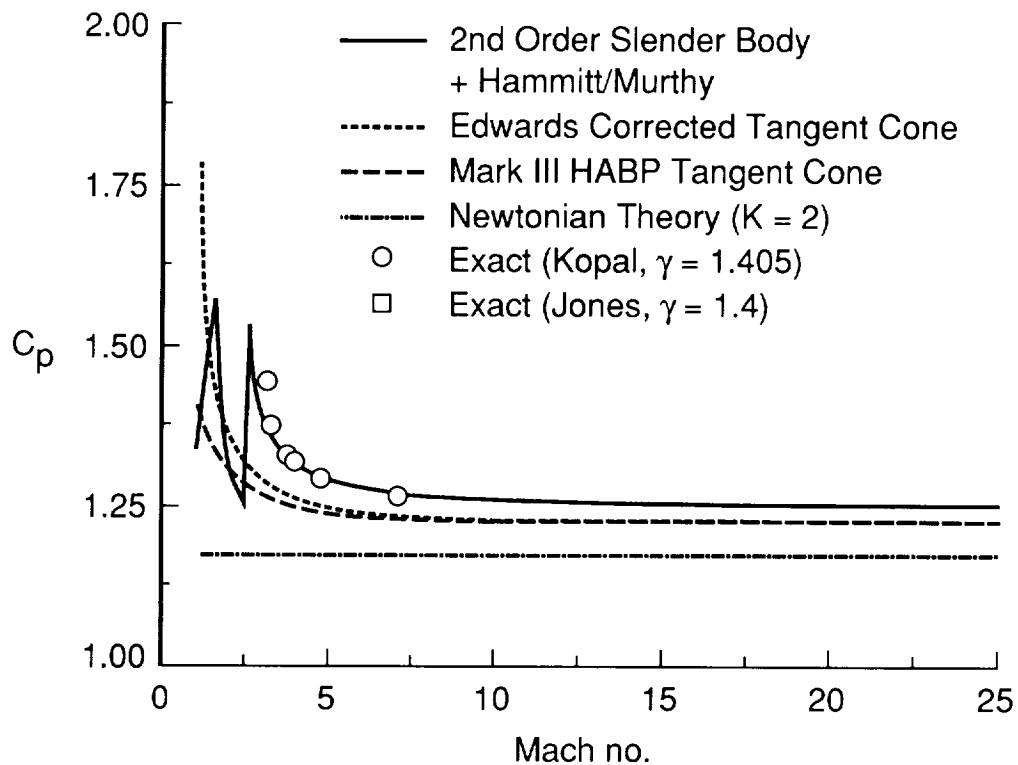


Figure 10. Pressure coefficient versus Mach number for 50° sharp cone.



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